Effects of Wrapping Method and Soil Contact on Hay Stored in Large Round Bales in Central Wisconsin

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Abstract. *A 2-yr study was conducted during 2006-2007 and 2007-2008 to evaluate the effects of outdoor weathering on the nutritive value, ruminal disappearance kinetics of dry matter (DM), and recoveries of DM from 1.4- × 1.2-m large-round bales. The study consisted of (n = 90) bales that were allocated within a 2 x 5 factorial arrangement of hay types [orchardgrass (*Dactylis glomerata *L.) or alfalfa (*Medicago sativa *L.)] and storage treatments. Bales were wrapped with either sisal twine or net, and they were positioned outdoors either elevated on wooden pallets or directly on the ground. For both hay types, positive controls were wrapped with net and stored indoors. Generally, the main effects of hay type and storage treatment did not interact, but both main effects interacted with year. During 2006-2007, wrapping with net did not improve recovery of DM compared to bales wrapped with twine (93.7% vs. 93.4%; P = 0.781), but recovery was improved by elevating bales on wooden pallets (95.0% vs. 92.1%; P < 0.001). However, control hays surpassed by 4.6 percentage units the overall recovery mean for all bales wintered outdoors (98.1% vs. 93.5%; P < 0.001). Precipitation was above normal during 2007-2008; this resulted in a 7.3-percentage-unit recovery advantage for indoor storage compared to all bales stored outdoors. Unlike the previous year, bales wrapped with twine and placed directly on the ground were especially vulnerable to weathering, recovering only 85.2% of initial DM, while recoveries for other treatments stored outdoors ranged from 89.6% to 91.1%. During the relatively dry conditions observed during 2006-2007, the energy density (total digestible nutrients; TDN) of the 0.15-m surface layer for all bales wintered outdoors was depressed, but by only 1.4 percentage units (60.8% vs. 59.4%; P = 0.017) relative to indoor controls. With much greater precipitation during 2007-2008, this differential increased only marginally (57.3% vs. 54.1%; P < 0.001). Generally, kinetic estimates obtained from *in situ* evaluations of ruminal disappearance of DM were consistent with responses observed for TDN. In summary, recoveries of DM from large-round bales always were greatest with indoor storage. The results of these studies suggest that elevating bales off of the soil surface and wrapping with net offer the highest probability of maximizing recovery of DM following outdoor winter storage in northern climates.*

Keywords. *Large-round bales, DM recovery, Nutritive value,* In-situ *disappearance.*

Throughout the north-central United States, the cost and availability of labor has forced many dairy producers to adopt large-rectangular or large-round baling techniques for legume or legume-grass hays. Losses of DM from large-round bales following extended outdoor storage can vary widely, ranging from 3% to 40%, and oftentimes, these losses are directly proportional to storage time (Rotz and Muck, 1994). Generally, outside storage of large-round bales has been a management practice utilized most commonly within beef cow-calf enterprises, rather than in dairy-production systems. In part, this occurs because the nutritional requirements of beef cows are substantially lower than those identified for dairy cows, and beef producers are more willing to accept the losses of DM and nutritive value that occur as a consequence of weathering. In addition, many beef cow-calf enterprises are relatively small, with the owner often maintaining full- or part-time employment off of the farm. As a result, minimizing out-of-pocket costs is critical to economic survival. Within this context, permanent indoor storage structures for hay often are considered an unnecessary luxury. For dairy producers, large-percentage losses of high-quality legume or legume-grass hays are unacceptable. However, the increased flexibility and ease of managing hay inventories, as well as the reduced risks of fire associated with outdoor storage, justify some in-depth evaluation of this practice.

Over the past three decades, many studies (Anderson et al., 1981; Collins et al., 1987; Huhnke, 1988; Huhnke, 1990; Russell et al., 1990; Huhnke, 1993; Harrigan and Rotz, 1994; Taylor et al., 1994; Collins et al., 1995; Turner et al., 2007; Shinners et al., 2009) have evaluated storage losses and changes in nutritive value for forage crops packaged in round bales wrapped with various methods and then stored under different conditions. Based on these and other studies, factors such as climate, storage time, storage method, and the species composition of the forage can affect both the recovery of DM and nutritive value of the hay when it is sold subsequently as a cash crop, or offered directly to livestock by producers (Harrigan and Rotz, 1994; Rotz and Muck, 1994).

Within the context of producer education, two recommendations mentioned frequently that theoretically improve recovery of DM include physical separation of each bale from the soil or grass sod (Rotz and Muck, 1994; Collins,

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1995; Pogue et al., 1996; Ball et al., 1998; Coblentz et al., 2002), and wrapping with plastic net to maintain a more uniform bale surface, thereby improving the water-shedding potential of the bale (Collins, 1995; Collins et al., 1995; Pogue et al., 1996). In practice, these recommendations have provided varying benefits when evaluated experimentally. Collins et al. (1995) reported improved recoveries of DM from round bales of tall fescue [*Lolium arundinaceum* (Schreb.) Darbysh] hays if they were wrapped with plastic net instead of conventional sisal twine. Similarly, Russell et al. (1990) observed a 4.7-percentage-unit improvement in recovery of DM from alfalfa-bromegrass (*Bromus inermis* Leyss.) hays wrapped with net compared to traditional sisal twine. Recently, Shinners et al. (2009) also reported significantly improved recoveries of DM from alfalfa-grass hays wrapped with net compared to bales wrapped with either sisal or plastic twine. In contrast, Taylor et al. (1994) concluded that the use of net wrap was not justified on the basis of reducing weathering losses, but these results may reflect the relatively arid climate in that study. Russell et al. (1990) found no advantage in recovery of DM by placing bales on a 15-cm-deep bed of crushed rock in order to break soil contact; however, this management technique restricted visual evidence of weathering, and also improved concentrations of *in vitro* DM disappearance. Turner et al. (2007) reported no improvement in recovery of mixed cool-season grass hays after 7 months of storage by elevating bales on wooden pallets compared to direct soil contact. After 15 months, there continued to be no differences on the basis of soil contact when bales were uncovered, but recoveries were improved by breaking soil contact when bales were covered.

In addition to these recommendations, there are several additional factors inherent within northern climates that may alter expected losses of DM from large hay packages relative to those observed typically in warmer climates. Mean monthly norms of temperature for Marshfield, Wisconsin, from November through March range from -0.4°C to -11.3°C (NOAA, 2002) and have direct relevance to outdoor hay storage because losses of DM occur not only as a result of leaching, but also via microbial activity that is exacerbated by moisture and warm temperatures (Rotz and Muck, 1994). Therefore, losses of DM could be less extensive in northern climates incurring cold winter periods compared to estimates derived from warm, moist environments outside the region (Harrigan et al., 1994). Conversely, it is also possible that cooler temperatures could slow the elimination of water from the bale following rainfall events, which could potentially have the opposite effect. Furthermore, it is relatively common throughout central Wisconsin for producers to establish perennial cool-season grasses, such as orchardgrass, within stands of alfalfa. In part, this serves as some insurance against winterkill of alfalfa, but it also potentially affects storage characteristics by including varying percentages of grasses within the bale; fine-leafed grasses often are assumed to shed water more efficiently than legumes during rainfall events (Rotz and Muck, 1994). Our objectives for this project were to assess storage characteristics, recoveries of DM, forage nutritive value, and *in situ* ruminal disappearance kinetics of DM for large-round bales containing majority percentages of either orchardgrass or alfalfa, wrapped with either sisal twine or net, and then stored outdoors over winter on wooden pallets or directly on the ground.

Materials and Methods

OrchardGrass Study

Experimental Hays (2006-2007)

A well-established 5.4-ha stand of 'Extend' orchardgrass located on a Withee silt loam soil at the University of Wisconsin Marshfield Agricultural Research Station (44°39 N; 90°08 W) was chosen for the study. The orchardgrass was frost-seeded on 1 April 2004; the alfalfa had been established several years previously (9 May 2001). Standing forage was mowed at 0900 h on 10 July 2006 with a Case-International Harvester mower-conditioner (Model 8830, J. I. Case Co., Racine, Wis.), and allowed to wilt until 1000 h on 12 July, when adjacent windrows were raked together with a side-delivery rake. Prior to raking, the proportions of orchardgrass and alfalfa in the forage mixture were quantified by walking the entire field in a zig-zag pattern, stopping randomly to take grab samples from windrows. This forage (~8 kg, wet basis) was then hand-separated into orchardgrass, alfalfa, various clovers, and weeds. Subsequently, each species group was dried to constant weight at 50°C, and then weighed to determine the composition of the sward on a percentage of total dry weight basis (81% orchardgrass, 15% alfalfa, 1% various clovers, and 3% other species and weeds). At harvest, the alfalfa was at the mid-bloom stage of growth, while the orchardgrass was entirely vegetative regrowth following an initial harvest on 26 May 2006.

Baling, Sampling, and Storage

At 1230 h on 12 July, hay was packaged with a Ford-New Holland round baler (Model BR 740A, CNH America, LLC, Racine, Wis.). Bales (1.4 × 1.2 m) were wrapped with either: i) two revolutions of plastic net or ii) conventional sisal twine with revolutions spaced at approximately 18 cm. Each bale was weighed with a hanging digital scale that was fastened to the front-end loader of a tractor. In addition, bale width, height, and diameter were determined with a tape measure, thereby allowing the calculation of the initial volume and DM density of each bale. Before bales were removed from the field, nine core samples that were 0.46 m deep and 2.5 cm in diameter were taken (manually) from the center portion of one side of each bale (fig. 1a) using a Uni-Forage Sampler (Star Quality Samplers, Edmonton, AB, Canada). Since the objective of the study was to assess the effects of weathering on stored hays, all sampling holes were filled immediately with spray-foam insulation to prevent air, sunlight, and moisture from having direct access into the bale core (fig. 2). Core samples were thoroughly mixed, composited (~400 g) within each bale, and dried to constant weight under forced air at 50°C to determine the initial concentration of DM. These samples were then retained in sealed freezer bags for subsequent analysis of nutritive value and *in situ* disappearance kinetics of DM. Following these initial sampling procedures, bales were placed directly on the ground (grass sod) without cover or elevated on a wooden pallet, thereby breaking soil contact. These procedures allowed establishment of five storage treatments in which

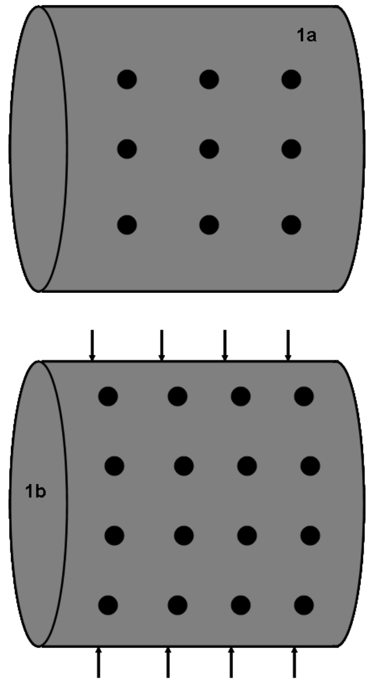

Figure 1. Illustration of sampling locations for large-round bales of mostly orchardgrass or mostly alfalfa hay made in Marshfield, Wis., during 2006 and 2007. The top figure (1a) represents sampling locations before storage (immediately after baling) made to a 0.46-m depth. The bottom illustration (1b) represents the 24 sampling locations on the opposite side of the bale from figure 1a made after the winter storage period. Arrows denote post-storage sampling locations on the top and bottom of the bale.

bales were wrapped with: i) sisal twine and placed directly on the ground outdoors (TW-GR; seven bales); ii) sisal twine and elevated on wooden pallets outdoors (TW-EL; six bales); iii) plastic net and placed directly on the ground outdoors (NET-GR; 5 bales); iv) plastic net and elevated on wooden pallets outdoors (NET-EL; five bales); and v) plastic net and elevated on wooden pallets located indoors (CONTROL; four bales). All bales stored outdoors were commingled randomly in short (4-bale) rows that were oriented in a north-south direction. When bales were placed for storage, at least 1 m of open space was allowed between adjacent bales on all sides. Bales remained undisturbed in these locations until a final evaluation of physical characteristics and sampling the following spring.

Final Sampling and Evaluation

On 17 April 2007, each bale was measured and weighed a second time using procedures identical to those described previously. The sisal twine used in these studies was prone to decompose during storage, especially when bales were placed directly on the ground. When TW-GR bales were lifted with the front-end loader before weighing, some hay occasionally adhered to the ground; this hay was considered to be lost DM, and no attempt was made to sample or quantitatively recover it. Unlike the sampling protocol for bales prior to storage, post-storage core-sampling procedures were more rigorous. Initially, the surface layer of all bales was sampled to a depth of 0.15 m. This surface-layer sample was a thoroughly-mixed composite of 24 probes spaced uniformly over the entire half of the bale surface that was directly opposite that of prestorage sampling sites (fig. 1b). Deep-core samples were then obtained with a 0.61-m probe (Uni-Forage Sampler; Star Quality Samplers, Edmonton, AB, Canada) powered with an electric drill. In order to prevent contamination of the deep-core samples with hay from the weathered surface layer, the 24 surface-layer probes were taken first, and then the deep-core samples were extracted from the same sampling holes (fig. 2). Respective totals of ~175 g and ~400 g of sample from the 24 surface and

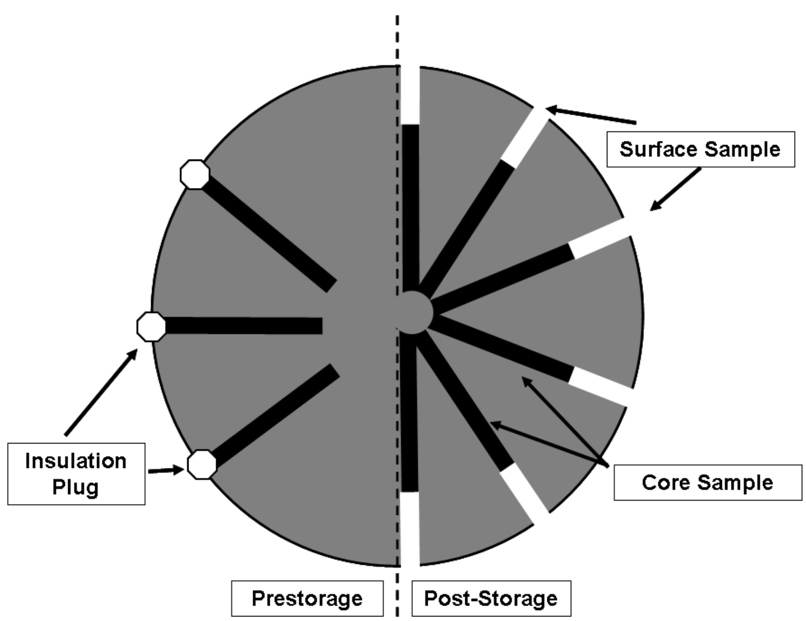

Figure 2. Endview of sampling locations for large-round bales of mostly orchardgrass or mostly alfalfa. Before storage (left), core samples were taken in the field with a manually operated probe to a depth of 0.46 m. Spray-foam insulation was used to immediately plug these holes and prevent air, water, and sunlight from accessing the interior of the bale during storage. After storage (right) bales were probed first to a depth of 0.15 m (surface sample, white portion) and then via the same holes to a depth of 0.61 m (core sample, black portion). Sampling locations at the top and bottom of the bale were normally accessed by rolling the bale; however, if this was not possible because of deformation (either by squatting or lost sisal twine), bales were raised with a front-end loader and cores were bored from underneath the raised bale.

deep-core probe sites were composited from each bale. All samples were dried to constant weight under forced air (50°C) to determine the moisture concentration within each bale layer. Samples were then retained for evaluation of nutritive value and *in-situ* disappearance kinetics of DM. Recoveries of DM for each bale were based on differences in DM weights before and after storage.

Experimental Hays (2007-2008)

The same experiment evaluating orchardgrass hays was repeated at the same field site the following year. Standing forage was mowed on 11 June, raked on 13 June, and subsequently baled at 1015 h on 15 June 2007 (23 total bales). On a percentage of DM basis, the hay was 74% orchardgrass and 23% alfalfa, with the balance (3%) comprised of weeds and various clovers. At least four bales were allocated randomly to each of the five baling treatments; however, one additional bale was assigned to TW-GR, TW-EL, and NET-GR. Procedures for measuring, weighing, sampling, storing bales were identical across years; however, hay baled in 2007 represented the initial growth of orchardgrass, which was fully headed, and differed from the vegetative regrowth harvested the previous year. The minority percentage of alfalfa had reached the mid-bloom stage of growth by the 11 June harvest date. Final evaluation of bales from the second year of the study occurred on 6 May 2008.

Alfalfa Study

Experimental Hays (2006-2007)

In conjunction with the orchardgrass study described previously, a parallel and simultaneous evaluation using identical experimental procedures was conducted with ‘Garst BD100’ alfalfa and volunteer quackgrass [*Elytrigia repens* (L.) Nevski]. The experimental site was immediately adjacent to the one described for the orchardgrass trials, and had the same Withee silt loam soil type. Alfalfa at this site had been established into a clean-tilled seedbed on 10 July 2002. Standing forage was mowed on 10 July, raked at 1030 h on 13 July, and then baled at 1500 h the same day. Alfalfa was harvested at the mid-bloom stage of growth and comprised 74% of the stand, while volunteer quackgrass was harvested at boot stage and contributed 23% of the total forage dry weight. A total of 20 bales were produced from this field site, which were allocated equally among the five storage treatments (four per treatment). One common outdoor storage site was used for both the orchardgrass and alfalfa portions of the project; within this storage site, bales with majority percentages of orchardgrass or alfalfa were not physically segregated, but were commingled without regard for hay type. After storage, final evaluation of these bales occurred on 17 April 2007. During the final evaluation process, bales of both hay types were evaluated and sampled in random order, with no attempt to segregate the order of final evaluation on the basis of predominant forage type.

Experimental Hays (2007-2008)

During the second year of evaluation, the same experimental field again was used to produce bales of predominantly alfalfa hay. Standing forage was mowed on 11 June, raked at 1100 h on 15 June, and then baled at 1500 h on the same day. A total of 20 bales were produced from this field site; these bales were allocated evenly across the five storage treatments (four per treatment). On a dry weight basis, the experimental forage was comprised of 61% alfalfa and 36% quackgrass. On 11 June, these forages were at the mid-bloom and boot stages of growth, respectively. After storage, the final evaluation of these bales was initiated on 6 May 2008 as described previously.

Precipitation and Temperature

During the first year of the project, a total of 512 mm of precipitation was recorded (table 1) from July 2006 through April 2007. This was below normal precipitation for Marshfield (NOAA, 2002) over this time period, representing a deficit of 128 mm. On a monthly basis, 30-yr norms for precipitation were reached only during December 2006 and February 2007, which were both months exhibiting sub-zero mean monthly temperatures (-3.6°C and -11.8°C, respectively). During the second year of bale storage, there was a precipitation surplus of 175 mm from June 2007 through April 2008. Considered monthly, above normal precipitation was observed during August, October, and

Table 1. Monthly total precipitation and mean temperature at Marshfield, Wis., for 2006 through 2008.

	Total Precipitation				Mean Temperature			
	2006[a]	2007[a]	2008[a]	30-yr	2006[a]	2007[a]	2008[a]	30-yr
Month		(mm)		Normal[b]		(°C)		Normal[b]
January		23	32	25		-6.8	-10.7	-11.3
February		26	29	22		-11.8	-11.6	-8.0
March		42	14	50		1.0	-4.8	-1.5
April		49	149	75		6.1	5.6	6.6
May		120	85	94		14.9	11.5	13.2
June	56	69		105	18.8	19.4		18.5
July	53	85		103	22.7	20.7		21.0
August	106	245		109	19.8	20.2		19.6
September	63	96		102	13.4	15.9		14.3
October	62	123		63	5.6	11.6		8.1
November	34	2		58	2.2	0.1		-0.4
December	54	76		33	-3.6	-9.1		-8.2

[a] Data gathered on site and obtained from University of Wisconsin Marshfield Agricultural Research Station.
[b] NOAA (2002).

December 2007, and January, February, and April 2008. Of these months, precipitation during August 2007 (245 mm), October 2007 (123 mm), and April 2008 (149 mm) ranged from 195% to 225% of the expected norms; positive mean monthly temperatures were recorded in each case (20.2°C, 11.6°C, and 5.6°C, respectively).

Laboratory Analysis of Hays

Hay samples dried under forced air were ground through a Wiley mill (Arthur H. Thomas, Philadelphia, Pa.) fitted with either a 1- or 2-mm screen. Portions of each sample ground through a 2-mm screen were stored in sealed plastic bags and retained for subsequent ruminal incubations *in situ*. Portions of each hay sample ground through a 1-mm screen were analyzed for nitrogen (N), neutral-detergent fiber (NDF), acid-detergent fiber (ADF), hemicellulose, cellulose, acid-detergent lignin, and whole-plant ash. Concentrations of N were quantified by a rapid combustion procedure (AOAC, 1998, Official Method 990.03; Elementar Americas, Inc., Mt. Laurel, N.J.), and crude protein (CP) was calculated by multiplying the percentage of N in each sample by 6.25. Analysis of NDF and other fiber components were conducted sequentially, using batch procedures outlined by ANKOM Technology Corp. (Fairport, N.Y.) for an ANKOM200 Fiber Analyzer. Neither sodium sulfite, nor heat-stable α-amylase was included in the NDF solution. Whole-plant ash was determined on 1.0-g subsamples of each hay, and calculated as the percentage of total plant DM remaining after combustion at 500°C for 2 h in a muffle furnace. For each bale, TDN was calculated for all hay samples, and was derived from the summative equation (NRC, 2001; Weiss et al., 1992) using the acid-detergent lignin option for estimating truly digestible fiber. These calculations also required estimates of residual CP that were insoluble in both neutral- and acid-detergent (NDICP and ADICP, respectively). These were obtained from composites of like bales (replicates) following nonsequential extraction in neutral and acid detergent, respectively. The extracting NDF solution contained no sodium sulfite or heat-stable α-amylase, and residual CP was determined following these extractions by the combustion procedure and the 6.25 conversion factor described previously.

In Situ Procedures

Selection of Hays

Excessive sample numbers prohibited the evaluation of kinetics of ruminal DM disappearance for all possible combinations of year, hay type (orchardgrass or alfalfa), storage treatment, and replication (bale). Characteristics of nutritive value within the bale core generally were unaffected by storage treatments; therefore, only samples obtained from the bale surface were subjected to ruminal *in situ* incubations. A total of 20 post-storage hays sampled from the 0.15-m surface layer were evaluated; each of these hays was a composite sample, with equal representation from all replications (bales) with an identical treatment structure. Therefore, the storage treatments evaluated for ruminal disappearance kinetics of DM included TW-GR, TW-EL, NET-GR, NET-EL, and CONTROL from both the orchardgrass and alfalfa studies in 2006-2007 (10 total treatments), and the same treatments from these studies repeated during 2007-2008 (10 total treatments). Four additional hays were evaluated to provide a comparison with kinetic characteristics immediately after baling (INITIAL). These included composites of bales from both hay types (orchardgrass and alfalfa) sampled before storage during both 2006-2007 and 2007-2008.

Animal Care

Two nonlactating 939 ± 12.8-kg ruminally cannulated Holstein cows were used for the ruminal incubations of weathered hays. Cannulations (Protocol #A-1307) and care of the cows (Protocol #A-1339) were approved by the Research Animal Resources Center of the University of Wisconsin. A basal diet consisting of chopped alfalfa-mixed grass hay (18.1% CP, 39.5% NDF, and 27.1% ADF), ground corn, and trace mineralized salt was offered to cows in equal portions at 0900 and 1500 h at a daily cumulative rate of 1.60% of BW. On an as-fed basis, the basal diet contained 94.6% alfalfa-mixed grass hay, 4.7% ground corn, and 0.7% trace mineralized salt; ground corn and salt were top-dressed at each feeding. Fresh water was available continuously on an *ad-libitum* basis, and the cows were adapted to the basal diet for 10 d prior to initiating the trial. Experimental hays were evaluated *in situ* in two experimental periods. After the 10-d adaptation to the basal diet, *in situ* analyses were conducted in both cows over a 4-d time interval (Period 1). After Period 1, cows were given a 3-d recovery period before initiating identical procedures during Period 2.

Incubation Procedures

In situ procedures were consistent with the standardized techniques described by Vanzant et al. (1998). Five-gram samples of dried forage were weighed into Dacron bags (10 cm × 20 cm; 50 ± 10-μm pore size; ANKOM Technology, Corp.). Bags were heat-sealed with an impulse sealer (Type TISH-200; TEWI International Co., Ltd., Taipei, Taiwan), placed in 35- × 50-cm mesh bags, and then incubated in tepid water (39°C) for 0.33 h. Samples were then inserted below the rumen mat and into the ventral rumen at 0800 h and then incubated for 3, 6, 9, 12, 24, 36, 48, 72, or 96 h. Upon removal from the rumen, bags were rinsed immediately in a top-loading washing machine. Rinsing procedures included 10 cold-water rinse cycles, where each cycle consisted of 1 min of agitation and 2 min of spin per rinse (Coblentz et al., 1997; Vanzant et al., 1998). A separate set of bags was pre-incubated and rinsed without ruminal incubation (0 h). After rinsing, all sample residues were dried to a constant weight under forced air at 50°C, and then allowed to equilibrate with the atmosphere in the laboratory prior to determining residual DM (Vanzant et al., 1996). With these procedures, the entire study included 960 Dacron bags. Therefore, for each of the four animal × period combinations, there were 240 total Dacron bags (24 hays × 10 time periods); of these, 216 bags were placed within the ventral rumen and 24 comprised the 0-h bags that were presoaked and rinsed without ruminal incubation.

Calculation of Disappearance Kinetics

The percentage of DM remaining at each incubation time was fitted to the nonlinear regression model of Mertens and Loften (1980) using PROC NLIN of SAS Institute (1990). This ruminal disappearance model partitions forage DM into three fractions based on relative susceptibility to ruminal disappearance. Fraction A was defined as the percentage of DM that disappeared from Dacron bags at a rate too fast to measure. Fraction B represented the portion of DM that disappeared at a measurable rate; and Fraction C was defined as the portion of DM that was unavailable in the rumen. Fractions B and C, disappearance rate (Kd), and the discrete lag time were determined directly by the nonlinear regression model. For each forage, Fraction A was calculated as 100% – (B + C), and the effective ruminal disappearance of DM was calculated as A + B x [Kd/(Kd + Kp)] (Ørskov and McDonald, 1979), where Kp = passage rate that was set arbitrarily at 0.06/h to make the results most relevant to lactating dairy cows (Hoffman et al., 1993). An independent ruminal DM disappearance curve was fitted for each combination of animal, period, and hay type, thereby resulting in a total of 96 DM disappearance curves for the entire project.

Statistics

Within year, data summarizing pre- and post-storage bale characteristics, as well as forage nutritive value were analyzed (PROC GLM; SAS Institute, 1990) as a completely randomized design with unequal replication of baling treatments. The number of bales made per treatment ranged from four to seven within each year of the study; our goal was to evaluate a minimum of four uniform bales/treatment/year, but additional bales also were evaluated when availability permitted. Treatments were structured in a 2 × 5 factorial arrangement of hay types (orchardgrass or alfalfa) and storage treatments (TW-GR, TW-EL, NET-GR, NET-EL, and CONTROL). Hay type and storage treatments, as well as their associated interaction, were tested for significance with the residual error mean square. Year also was included within the model, and was tested for significance with replication (bale) within year serving as the error term. All interactions of other treatment effects with year were tested with the residual error mean square. Mean separation was conducted using single-degree-of-freedom orthogonal contrasts.

Data describing the ruminal disappearance kinetics of DM for the 0.15-m surface layer were analyzed as a randomized complete block design with a 2 × 2 × 6 factorial arrangement of years, hay types, and storage treatments (TW-GR, TW-EL, NET-GR, NET-EL, CONTROL, and INITIAL). The blocking effect was constructed as a 2 × 2 factorial arrangement of animal and period, which allowed for partitioning of the blocking effect into sums of squares for period, animal, and their associated interaction. Mean separation again was conducted with single-degree-of-freedom orthogonal contrasts. Throughout the entire study, statistical significance was declared at the P = 0.05 level of confidence with trends identified at P = 0.10 when they were relevant to the interpretation of results.

Results

Physical Bale Characteristics

Prestorage Assessment of Hays

Before storage, all physical bale characteristics except for bale diameter (P = 0.871) and bale volume (P = 0.288) were strongly affected (P < 0.001) by the interaction of hay type and year. Other interactions with year were largely undetected (P > 0.05). Similarly, the main effect of storage treatment, as well as all associated interactions had little effect on results; therefore, prestorage data are presented and discussed as hay type × year interaction means (table 2). Although the respective concentrations of DM differed (P < 0.001) between orchardgrass and alfalfa hays during both 2006 (90.8% vs. 88.7%) and 2007 (88.8% vs. 92.5%), all hays were within the 85% DM threshold for acceptable storage suggested by Rotz and Muck (1994) that should largely eliminate spontaneous heating within this bale type at the initiation of storage. Initial wet weights and DM densities were greater (P < 0.001) for orchardgrass hays compared to alfalfa hays during 2006-2007. Averaged across all bales produced that year, these differentials favored orchardgrass by 40 kg and 16 kg/m^3, respectively. Bales of greater density are considered to be more effective at repelling rainfall, and an equation describing DM losses has been developed (Harrigan et al., 1994) in which bale density has a limiting effect on losses of DM. Previously, Russell et al. (1990) found no difference in recovery of DM from high- and low-density alfalfa-bromegrass hays stored outdoors for 4 or 9 months. Curiously, differences in DM densities were not observed (P = 0.302) across hay types during 2007-2008, although

Table 2. Initial bale characteristics for bale weathering studies with mostly orchardgrass or mostly alfalfa hays conducted at Marshfield, Wis., during 2006 and 2007.

Treatment		Bales			Volume	Wet Weight	DM	DM Density
Year	Hay Type	(No.)	Diameter (m)	Width (m)	(m^3)	(kg)	(%)	(kg/m^3)
2006	Orchardgrass[a]	27	1.35	1.19	1.70	328	90.8	175
	Alfalfa[b]	20	1.32	1.17	1.61	288	88.7	159
2007	Orchardgrass[c]	23	1.37	1.17	1.73	294	88.8	152
	Alfalfa[d]	20	1.35	1.17	1.67	277	92.5	154
	SEM	. . .	0.006	0.002	0.016	2.7	0.28	1.6
Contrasts			*P > F*					
2006: Orchardgrass vs. alfalfa		. . .	0.005	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
2007: Orchardgrass vs. alfalfa		. . .	0.010	0.835	0.012	< 0.001	< 0.001	0.302

[a] Comprised of 81% orchardgrass and 15% alfalfa.
[b] Comprised of 74% alfalfa and 23% grass (mostly quackgrass).
[c] Comprised of 74% orchardgrass and 23% alfalfa.
[d] Comprised of 61% alfalfa and 36% grass (mostly quackgrass).

orchardgrass bales were heavier (P < 0.001) by 17 kg on a wet weight basis. Wet-weight differences during the second year can be explained largely on the basis of a greater (P < 0.001) concentration of DM in the alfalfa hay (92.5% vs. 88.8%).

Post-Storage Assessment 2006-2007

For post-storage physical characteristics of experimental bales, main effects of both hay type and storage method generally interacted with year, but not with each other. Furthermore, no response variable exhibited a three-way interaction (P ≥ 0.236) of main effects. For these reasons, the hay type and storage method main effects are presented and discussed by year (tables 3 and 4). During 2006-2007 (table 3), the final concentration of DM within the 0.15-m surface layer (87.3%) of CONTROL bales was similar numerically to that within the bale core (88.7%), and also represented little practical change from that observed at baling the previous summer (89.9%). These observations suggest that the combination of structural cover coupled with a physical barrier breaking contact with the concrete floor was effective in preventing absorption of moisture by CONTROL hays. The CONTROL hays differed from all those stored outside by exhibiting reduced final wet weights (300 vs. 312 kg; P = 0.016) that occurred largely as a result of a drier surface layer (87.3% vs. 77.5% DM; P < 0.001). As a result of these factors, CONTROL hays exhibited greater recoveries of initial forage DM (98.1% vs. 93.5%; P < 0.001) than those wintered outdoors. Final DM densities for CONTROL bales did not differ (P = 0.449) from all other hays wintered outdoors.

Bales wrapped with net have been theorized to provide a uniformly compressed exterior surface compared to twine-wrapped bales, thereby aiding in the shedding of water from the bale surface (Pogue et al., 1996). Recently, Shinners et al. (2009) showed that there was approximately three times more loss of DM from bales of mixed grass-alfalfa hay wrapped with twine compared to those secured with plastic net, and that most of these losses were observed to be alfalfa leaves. This potentially could increase the penetration of water during rainfall events by creating a coarser bale surface that is less likely to form a water-resistant thatch. However, our bales wrapped with net did not differ from those wrapped with twine for any final bale characteristic (P ≥ 0.154), and respective final recoveries of DM were virtually identical (93.7 vs. 93.4%; P = 0.781).

Unlike wrapping method, establishment of a physical barrier between the bales and the grass sod positively affected numerous final bale characteristics. Bales stored outdoors and directly on the ground exhibited greater final wet weights than those elevated on wooden pallets (316 vs. 307 kg; P = 0.031), which can be explained in part by the respective reduced concentrations of DM within the 0.15-m surface layer (70.7% vs. 84.6%; P < 0.001). Breaking physical contact between the ground and the bale did not affect (P = 0.486) concentrations of DM at the bale core, but resulted in improved recoveries of DM (95.0% vs. 92.1%; P < 0.001). The effects of breaking soil contact were completely independent of wrapping method; no interaction of wrapping method and soil contact was observed for any response variable (P ≥ 0.300). After storage, orchardgrass hays exhibited greater final wet weights (P < 0.001) and DM densities (P < 0.001) than alfalfa hays, but these were largely carryover effects that also were detected immediately after baling (table 2).

Table 3. Final bale characteristics for large-round bales of mostly orchardgrass or mostly alfalfa stored from July 2006 until April 2007 in Marshfield, Wis.

Treatment				DM			
Wrapping Type	Storage Site	Bales (No.)	Wet Weight (kg)	Surface (%)	Core (%)	DM Density (kg/m^3)	DM Recovery (%)
Storage Treatments							
Net	Control[a]	8	300	87.3	88.7	159	98.1
Net	Elevated[b]	9	310	84.1	87.5	163	95.0
	Ground[c]	9	314	69.5	87.5	154	92.3
Sisal twine	Elevated	10	305	85.0	87.7	154	94.9
	Ground	11	317	71.7	87.0	153	92.0
	SEM	. . .	4.0	1.83	0.55	3.6	0.77
Hay Type							
	Orchardgrass[d]	27	332	80.2	88.3	167	94.8
	Alfalfa[e]	20	287	78.9	87.1	146	94.1
	SEM	. . .	2.5	1.17	0.35	2.3	0.49
Contrasts			*P > F*				
1) Control vs. all outside		. . .	0.016	< 0.001	0.055	0.449	< 0.001
2) Net wrap vs. sisal twine[f]		. . .	0.788	0.386	0.839	0.154	0.781
3) Elevated vs. ground[f]		. . .	0.031	< 0.001	0.486	0.213	< 0.001
4) Interaction[f][g]		. . .	0.300	0.726	0.511	0.294	0.878
5) Orchardgrass vs. alfalfa		. . .	< 0.001	0.436	0.020	< 0.001	0.333

[a] Bales wrapped with net and stored under roof on wooden pallets.
[b] Bales stored outdoors without cover on wooden pallets.
[c] Bales stored outdoors without cover and placed directly on the ground.
[d] Comprised of 81% orchardgrass and 15% alfalfa.
[e] Comprised of 74% alfalfa and 23% grass (mostly quackgrass).
[f] Excludes control bales.
[g] Interaction of contrast #2 and #3.

Table 4. Final bale characteristics for large-round bales of mostly orchardgrass or mostly alfalfa stored from June 2007 until May 2008 in Marshfield, Wis.

Treatment		Bales		DM		DM Density	
Wrapping Type	Storage Site	(No.)	Wet Weight (kg)	Surface (%)	Core (%)	(kg/m^3)	DM Recovery (%)
Storage Treatments							
Net	Control[a]	8	276	87.6	89.4	150	96.4
Net	Elevated[b]	8	288	75.3	86.4	171	91.1
	Ground[c]	9	291	68.1	87.0	180	89.6
Sisal twine	Elevated	9	287	76.6	86.6	160	90.8
	Ground	9	277	74.3	84.7	153	85.2
	SEM	...	4.0	1.83	0.55	3.6	0.77
Hay Type							
	Orchardgrass[d]	23	294	76.6	86.9	164	93.2
	Alfalfa[e]	20	274	76.1	86.8	162	88.1
	SEM	...	2.5	1.17	0.35	2.3	0.49
Contrasts			$P > F$				
1) Control vs. all outside		...	0.038	< 0.001	< 0.001	< 0.001	< 0.001
2) Net wrap vs. sisal twine[f]		...	0.062	0.050	0.060	< 0.001	0.003
3) Elevated vs. ground[f]		...	0.403	0.012	0.271	0.835	< 0.001
4) Interaction[f],[g]		...	0.076	0.187	0.030	0.028	0.010
5) Orchardgrass vs. alfalfa		...	< 0.001	0.788	0.762	0.681	< 0.001

[a] Bales wrapped with net and stored under roof on wooden pallets.
[b] Bales stored outdoors without cover on wooden pallets.
[c] Bales stored outdoors without cover and placed directly on the ground.
[d] Comprised of 74% orchardgrass and 23% alfalfa.
[e] Comprised of 61% alfalfa and 36% grass (mostly quackgrass).
[f] Excludes control bales.
[g] Interaction of contrast #2 and #3.

Post-Storage Assessment 2007-2008

The CONTROL hays differed ($P \leq 0.038$) from all hays stored outdoors across all response variables during 2007-2008 (table 4). Most notably, CONTROL hays exhibited reduced wet weights (276 vs. 286 kg; $P = 0.038$) that were largely the result of a much drier bale surface layer (87.6% vs. 73.5% DM; $P < 0.001$). Although the CONTROL hays also were drier at the bale core (89.4% vs. 86.2% DM; $P < 0.001$), the magnitude of this differential was relatively small (3.2 percentage units), and of questionable relevance. The most beneficial practical aspect of indoor storage was that CONTROL bales exhibited a 7.3-percentage unit advantage for recovery of DM (96.4% vs. 89.1%; $P < 0.001$) than bales stored outdoors. Unlike the previous year, the surface layer of bales stored outdoors exhibited greater concentrations of DM when wrapped with twine compared to those wrapped with net (75.5% vs. 71.5% DM; $P = 0.050$); however, hays elevated on wooden pallets again had a drier surface layer than hays placed directly on the soil surface (76.0% vs. 71.2% DM; $P = 0.012$). More importantly, there were interactions between wrapping method and soil contact with respect to recovery of DM ($P = 0.010$). Generally, recoveries of DM for TW-EL, NET-GR, and NET-EL were comparable, ranging from 89.6% to 91.1%, while recoveries for TW-GR were poorer (85.2%). Although not compared statistically, recoveries of DM for all bales stored outdoors were lower (89.1%) during 2007-2008 than during the previous year (93.5%); this likely was related to differences in precipitation across the two storage seasons (table 1). Under the wetter storage conditions of 2007-2008, recoveries of DM were greater for orchardgrass hays compared to those comprised primarily of alfalfa (93.2% vs. 88.1%; $P < 0.001$). This supports the premise that fine-leafed grasses possess superior water-shedding properties compared to other hays (Rotz and Muck, 1994). During the drier conditions observed during the previous year, recoveries of DM were virtually identical across hay types (table 3).

Forage Nutritive Value

Prestorage Assessment of Hays

When sampled before storage, most indices of nutritive value exhibited significant effects of year, hay type, and their associated interaction. Other effects and interactions were largely nonsignificant; therefore, prestorage data for each hay type are presented (table 5) and discussed by year. Hay types differed across all measures of nutritive value for bales produced during July 2006. These differences were largely predictable; predominantly alfalfa hay exhibited greater concentrations of CP ($P < 0.001$), ADF ($P = 0.045$), and acid-detergent lignin ($P < 0.001$), while concentrations of other fiber components ($P \leq 0.005$), whole-plant ash ($P < 0.001$), and TDN ($P = 0.038$) were greater for orchardgrass hays. Similar responses were observed for hays produced during June 2007, except that orchardgrass hays were greater in concentrations of ADF than alfalfa hays (38.4% vs. 36.4%; $P < 0.001$), and whole-plant ash did not differ ($P = 0.176$) across hay types. Generally the greater concentrations of fiber components for orchardgrass and alfalfa hays produced during the second year can be explained on the basis of developed stems within the orchardgrass hays, which were not present in the vegetative regrowth harvested the previous year, and by the greater proportion of volunteer quackgrass in alfalfa hays compared to hays produced during 2006. Estimates of TDN differed across hay types within each

Table 5. Assessment of nutritive value at baling for weathering studies using mostly orchardgrass or mostly alfalfa hays conducted at Marshfield, Wis., during 2006 and 2007.

Treatment									
Year	Hay Type	CP	NDF	ADF	Hemicellulose	Cellulose	Lignin	Ash	TDN
		(% of DM)							
2006	Orchardgrass[a]	11.5	50.9	29.7	21.2	25.3	3.85	10.3	60.8
	Alfalfa[b]	15.2	44.9	30.4	14.6	24.5	5.29	9.5	60.2
2007	Orchardgrass[c]	10.4	64.6	38.4	26.2	33.6	4.05	9.3	57.7
	Alfalfa[d]	14.9	55.5	36.4	19.1	30.3	5.42	9.5	56.4
	SEM	0.14	0.37	0.25	0.26	0.21	0.077	0.13	0.20
Contrasts		*P > F*							
2006: Orchardgrass vs. alfalfa		< 0.001	< 0.001	0.045	< 0.001	0.005	< 0.001	< 0.001	0.038
2007: Orchardgrass vs. alfalfa		< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.176	< 0.001

[a] Comprised of 81% orchardgrass and 15% alfalfa.
[b] Comprised of 74% alfalfa and 23% grass (mostly quackgrass).
[c] Comprised of 74% orchardgrass and 23% alfalfa.
[d] Comprised of 61% alfalfa and 36% grass (mostly quackgrass).

evaluation year (P = 0.038 and < 0.001 for 2006 and 2007, respectively), but the respective magnitudes of these differences (0.6 and 1.3 percentage units) were of only minor nutritional relevance.

Post-Storage Assessment of Surface Layer (2006-2007)

Year × storage treatment and year × hay-type interactions were significant for numerous indices of nutritive value. However, the hay type × storage treatment interaction and the three-way interaction of year, hay type, and storage treatment generally were not. Therefore, storage treatment and hay type main effects are presented and discussed by year (tables 6 and 7). During 2006-2007 (table 6), the 0.15-m surface layer of CONTROL hays exhibited lower concentrations of CP (13.3% vs. 14.3%; P = 0.038), NDF (49.2% vs. 52.5% P = 0.001), ADF (30.6% vs. 31.9%; P = 0.016), and hemicellulose (18.5% vs. 20.6%; P < 0.001), and a greater estimate of TDN (60.8% vs. 59.4%; P = 0.017) than all bales wintered outdoors. No differences (P ≥ 0.068) were detected for cellulose, acid-detergent lignin, or whole-plant ash, although each of these forage components exhibited numerically greater concentrations within bales wintered outdoors. Increased concentrations of fiber components at the bale surface of weathered bales compared to either bales stored indoors or to deep-core samples from bales stored outdoors are consistent with past work (Anderson et al., 1981;

Table 6. Final nutritive characteristics for the surface layer (0.15-m depth) of large-round bales of mostly orchardgrass or mostly alfalfa stored from July 2006 until April 2007 at Marshfield, Wis.

Wrapping Type	Storage Site	CP	NDF	ADF	Hemicellulose	Cellulose	Lignin	Ash	TDN
Storage Treatments		(% of DM)							
Net	Control[a]	13.3	49.2	30.6	18.5	25.2	4.80	9.3	60.8
Net	Elevated[b]	14.3	51.0	30.9	20.1	25.7	4.53	10.0	60.4
	Ground[c]	14.2	53.5	32.3	21.2	26.6	4.83	9.7	59.3
Sisal twine	Elevated	14.9	52.5	31.9	20.6	26.2	4.96	9.8	59.5
	Ground	13.9	52.8	32.2	20.6	26.1	5.18	10.1	58.5
	SEM	0.41	0.81	0.56	0.48	0.47	0.187	0.28	0.47
Hay Type									
	Orchardgrass[d]	12.3	53.7	30.7	23.0	26.0	3.78	10.0	61.2
	Alfalfa[e]	16.0	49.9	32.5	17.4	25.9	5.94	9.6	58.2
	SEM	0.26	0.52	0.36	0.30	0.30	0.119	0.18	0.30
Contrasts		*P > F*							
1) Control vs. all outside		0.038	0.001	0.016	< 0.001	0.098	0.721	0.068	0.017
2) Net wrap vs. sisal twine[f]		0.677	0.570	0.232	0.930	0.971	0.037	0.620	0.078
3) Elevated vs. ground[f]		0.155	0.073	0.039	0.217	0.375	0.159	0.887	0.030
4) Interaction[f][g]		0.308	0.177	0.195	0.242	0.254	0.818	0.361	0.986
5) Orchardgrass vs. alfalfa		< 0.001	< 0.001	< 0.001	< 0.001	0.681	< 0.001	0.164	< 0.001

[a] Bales wrapped with net and stored under roof on wooden pallets.
[b] Bales stored outdoors without cover on wooden pallets.
[c] Bales stored outdoors without cover and placed directly on the ground.
[d] Comprised of 81% orchardgrass and 15% alfalfa.
[e] Comprised of 74% alfalfa and 23% grass (mostly quackgrass).
[f] Excludes control bales.
[g] Interaction of contrast #2 and #3.

Table 7. Final nutritive characteristics for the surface layer (0.15-m depth) of large-round bales of mostly orchardgrass or mostly alfalfa stored from June 2007 until May 2008 at Marshfield, Wis.

Wrapping Type	Storage Site	CP	NDF	ADF	Hemicellulose	Cellulose	Lignin	Ash	TDN
Storage Treatments		(% of DM)							
Net	Control[a]	12.2	61.7	37.5	24.3	32.1	4.46	9.5	57.3
Net	Elevated[b]	13.7	62.6	37.7	25.1	31.4	5.15	10.9	54.8
	Ground[c]	13.9	62.5	38.6	23.9	31.5	5.85	10.6	53.6
Sisal twine	Elevated	13.1	64.3	39.0	25.2	32.7	5.38	10.6	54.0
	Ground	13.3	63.6	38.6	25.0	32.2	5.41	10.7	54.2
	SEM	0.41	0.81	0.56	0.48	0.47	0.187	0.28	0.47
Hay Type									
	Orchardgrass[d]	11.0	67.2	39.0	28.2	33.6	4.37	10.2	55.7
	Alfalfa[e]	15.5	58.7	37.6	21.2	30.4	6.14	10.7	53.9
	SEM	0.26	0.52	0.36	0.30	0.30	0.119	0.18	0.30
Contrasts		*P > F*							
1) Control vs. all outside		0.006	0.095	0.139	0.338	0.784	< 0.001	0.001	< 0.001
2) Net wrap vs. sisal twine[f]		0.131	0.081	0.246	0.210	0.051	0.564	0.777	0.823
3) Elevated vs. ground[f]		0.574	0.608	0.631	0.135	0.695	0.060	0.904	0.318
4) Interaction[f],[g]		0.985	0.731	0.255	0.254	0.574	0.082	0.477	0.182
5) Orchardgrass vs. alfalfa		< 0.001	< 0.001	0.007	< 0.001	< 0.001	< 0.001	0.047	< 0.001

[a] Bales wrapped with net and stored under roof on wooden pallets.
[b] Bales stored outdoors without cover on wooden pallets.
[c] Bales stored outdoors without cover and placed directly on the ground.
[d] Comprised of 74% orchardgrass and 23% alfalfa.
[e] Comprised of 61% alfalfa and 36% grass (mostly quackgrass).
[f] Excludes control bales.
[g] Interaction of contrast #2 and #3.

Russell et al., 1990; Collins et al., 1995; Norman et al., 2007; Turner et al., 2007). Presumably, these responses are caused by leaching of soluble forage compounds (especially sugars) during rainfall events, reactivated microbial respiration at the bale surface, or both. Although concomitant increases in concentrations of CP have been observed less consistently, trends similar to those reported in this study also have been described (Collins et al., 1995; Norman et al., 2007; Turner et al., 2007). The mechanism driving this response is likely to be similar to that described for fiber components; sugars and other compounds are preferentially leached, or oxidized via microbial respiration, thereby increasing concentrations of CP indirectly.

Comparisons of net and sisal-twine wrappings were largely nonsignificant ($P \geq 0.232$); however, bales wrapped with twine exhibited greater concentrations of acid-detergent lignin than bales wrapped with net (5.08% vs. 4.68%; $P = 0.037$). Similarly, differences were observed only for ADF ($P = 0.039$) and TDN ($P = 0.030$) when the surface layer of bales elevated on wooden pallets was compared with those from bales wintered on the ground. No other measure of nutritive value exhibited differences on the basis of soil contact ($P \geq 0.073$), nor were interactions observed ($P \geq 0.177$) between wrapping method and soil contact for any response variable. Orchardgrass and alfalfa hays differed ($P < 0.001$) across all indices of nutritive value except for concentrations of cellulose ($P = 0.681$) and whole-plant ash ($P = 0.164$). Although concentrations of CP and fiber components within the surface layer of both hay types were generally greater than those observed immediately after baling (table 5), there was little evidence to suggest that weathering affected hay types disproportionately.

Post-Storage Assessment of Surface Layer (2007-2008)

Although hay stored from 2007-2008 received much greater precipitation during storage than hay from the previous year (table 1), the effects of storage method on nutritive value were limited (table 7). Bales wrapped with sisal twine tended to exhibit greater concentrations of NDF ($P = 0.081$) and cellulose ($P = 0.051$) than bales wrapped with plastic net, but no other measure of nutritive value was affected ($P \geq 0.131$). Direct soil contact tended to increase ($P = 0.060$) concentrations of lignin relative to bales elevated on pallets, but no other response variable was affected ($P \geq 0.135$). Similarly, the tying method × soil contact interaction tended to be significant ($P = 0.082$) only for acid-detergent lignin, but not for any other measure of nutritive value ($P \geq 0.182$). While there were only limited detectable effects of storage treatment among bales stored outdoors during 2007-2008, weathered bales collectively exhibited greater concentrations of CP (13.5% vs. 12.2%; $P = 0.006$), acid-detergent lignin (5.46% vs. 4.46%; $P < 0.001$), and whole-plant ash (10.7% vs. 9.5%; $P = 0.001$) than CONTROL bales. These differences also resulted in reduced estimates of energy density within the surface layer of weathered bales relative to CONTROL bales (54.1% vs. 57.3% TDN; $P < 0.001$), which was consistent with observations during 2006-2007. Consistent with trends observed for 2006-2007, the nutritive value of orchardgrass hays differed ($P \leq 0.047$) from alfalfa hays across all response variables; however, there again was little evidence suggesting that the effects of weathering affected hay types disproportionately.

Post-Storage Assessment of the Bale Core (2006-2007)

Measures of nutritive value at the bale core were most frequently affected by year × hay type and year × storage treatment interactions, but generally not by the hay type × storage treatment or year × hay type × storage treatment interactions. Therefore, main effects of storage treatment and hay type are presented and described by year (tables 8 and 9). During 2006-2007 (table 8), CONTROL bales did not differ from bales wintered outdoors for any response variable ($P \geq 0.203$). Wrapping with net offered no practical advantage over conventional sisal twine; small differences (4.23% vs. 4.54%; $P = 0.022$) were detected between wrapping methods only for concentrations of acid-detergent lignin, but not for any other response variable ($P \geq 0.077$). Similarly, soil contact did not affect ($P \geq 0.577$) any measure of nutritive value at the bale core, nor did the tying method × soil contact interaction ($P \geq 0.370$). Orchardgrass bales differed ($P \leq 0.003$) from alfalfa bales for all measures of nutritive value except ADF ($P = 0.102$) and whole-plant ash ($P = 0.093$); however, these differences were largely artifacts of characteristics observed at baling (table 5).

Post-Storage Assessment of the Bale Core (2007-2008)

Unlike 2006-2007, there were detectable differences at the bale core for 6 of 8 response variables ($P \leq 0.034$) when CONTROL bales were compared with bales wintered outdoors (table 9). Only concentrations of hemicellulose ($P = 0.193$) and whole-plant ash ($P = 0.764$) did not differ as a result of outdoor storage. Although this seems in contrast with the previous year, the magnitude of most of these differences was relatively small, and the concentration of TDN was actually greater (57.7% vs. 56.4%; $P = 0.001$) within the core of bales wintered outdoors than for CONTROL bales. Concentrations of NDF ($P = 0.001$), ADF ($P = 0.021$), hemicellulose ($P = 0.009$), and cellulose ($P = 0.011$) were greater for bales wrapped with sisal twine compared to net, but the magnitude of these differences again was small, and concentrations of TDN varied ($P = 0.044$) by only 0.7 percentage units between the two wrapping methods. Bales elevated on wooden pallets exhibited greater concentrations of CP (13.5% vs. 13.0%; $P = 0.023$) and hemicellulose (24.0 vs. 23.0%; $P = 0.034$), as well as lower concentrations of ADF (34.9% vs. 35.7%; $P = 0.024$), but these differentials again were small, and concentrations of TDN did not differ ($P = 0.172$) on the basis of soil contact. There were no interactions of wrapping method and soil contact for any measure of nutritive value ($P \geq 0.109$). Orchardgrass and alfalfa hays exhibited differing ($P < 0.001$) concentrations of CP and fiber components following storage; however, these again reflected residual differences existing prior to storage, and final respective concentrations of TDN did not differ across hay types (57.4% vs. 57.6%; $P = 0.438$).

RUMINAL *IN SITU* DISAPPEARANCE KINETICS OF DM

Considered across ruminal kinetic parameters, main effects of year, hay type, and storage treatment interacted inconsistently; however, the strongest and most consistent interactions were found for year × hay type and year × storage treatment. Therefore, main effects of storage treatment and hay type are presented and discussed by year (tables 10 and 11). During 2006-2007 (table 10), Fractions A and B differed

Table 8. Final nutritive characteristics for the core of large-round bales of mostly orchardgrass or mostly alfalfa stored from July 2006 until April 2007 at Marshfield, Wis.

Wrapping Type	Storage Site	CP	NDF	ADF	Hemicellulose	Cellulose	Lignin	Ash	TDN
Storage Treatments		(% of DM)							
Net	Control[a]	14.5	46.8	28.7	18.1	23.3	4.37	9.5	61.9
Net	Elevated[b]	14.3	47.0	28.7	18.3	23.8	4.27	9.6	61.8
	Ground[c]	14.4	47.8	29.1	18.7	24.0	4.20	9.5	62.0
Sisal twine	Elevated	14.6	46.9	29.1	17.9	23.7	4.52	9.3	62.0
	Ground	14.5	46.7	29.1	17.6	23.7	4.55	9.5	61.7
	SEM	0.24	0.53	0.34	0.42	0.30	0.134	0.22	0.32
Hay Type									
	Orchardgrass[d]	12.4	50.4	29.2	21.3	24.6	3.58	9.7	62.3
	Alfalfa[e]	16.5	43.6	28.7	15.0	22.7	5.18	9.3	61.4
	SEM	0.16	0.35	0.22	0.27	0.19	0.085	0.14	0.21
Contrasts		*P > F*							
1) Control vs. all outside		0.830	0.615	0.415	0.999	0.203	0.934	0.968	0.980
2) Net wrap vs. sisal twine[f]		0.506	0.300	0.588	0.077	0.593	0.022	0.440	0.825
3) Elevated vs. ground[f]		0.835	0.656	0.577	0.870	0.806	0.952	0.648	0.856
4) Interaction[f],[g]		0.617	0.370	0.634	0.416	0.698	0.733	0.513	0.471
5) Orchardgrass vs. alfalfa		< 0.001	< 0.001	0.102	< 0.001	< 0.001	< 0.001	0.093	0.003

[a] Bales wrapped with net and stored under roof on wooden pallets.
[b] Bales stored outdoors without cover on wooden pallets.
[c] Bales stored outdoors without cover and placed directly on the ground.
[d] Comprised of 81% orchardgrass and 15% alfalfa.
[e] Comprised of 74% alfalfa and 23% grass (mostly quackgrass).
[f] Excludes control bales.
[g] Interaction of contrast #2 and #3.

Table 9. Final nutritive characteristics for the core of large-round bales of mostly orchardgrass or mostly alfalfa stored from June 2007 until May 2008 at Marshfield, Wis.

Wrapping Type	Storage Site	CP	NDF	ADF	Hemicellulose	Cellulose	Lignin	Ash	TDN
Storage Treatments		(% of DM)							
Net	Control[a]	12.4	60.7	36.7	24.1	31.5	4.67	10.3	56.4
Net	Elevated[b]	13.7	58.0	34.6	23.4	29.5	4.24	10.3	58.0
	Ground[c]	13.2	57.7	35.1	22.4	29.8	4.42	10.1	58.1
Sisal twine	Elevated	13.4	59.7	35.1	24.5	30.0	4.21	10.2	57.9
	Ground	12.8	59.9	36.2	23.6	30.8	4.47	10.4	56.9
	SEM	0.24	0.53	0.34	0.42	0.30	0.134	0.22	0.32
Hay Type									
	Orchardgrass[d]	10.8	65.6	37.2	27.3	32.6	3.79	10.4	57.4
	Alfalfa[e]	15.4	53.8	33.9	19.9	28.0	5.02	10.0	57.6
	SEM	0.16	0.35	0.22	0.27	0.19	0.085	0.14	0.21
Contrasts		$P > F$							
1) Control vs. all outside		0.002	0.004	< 0.001	0.193	< 0.001	0.034	0.764	0.001
2) Net wrap vs. sisal twine[f]		0.110	0.001	0.021	0.009	0.011	0.922	0.634	0.044
3) Elevated vs. ground[f]		0.023	0.950	0.024	0.034	0.091	0.114	0.980	0.172
4) Interaction[f],[g]		0.794	0.599	0.401	0.906	0.380	0.758	0.346	0.109
5) Orchardgrass vs. alfalfa		< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.064	0.438

[a] Bales wrapped with net and stored under roof on wooden pallets.
[b] Bales stored outdoors without cover on wooden pallets.
[c] Bales stored outdoors without cover and placed directly on the ground.
[d] Comprised of 74% orchardgrass and 23% alfalfa.
[e] Comprised of 61% alfalfa and 36% grass (mostly quackgrass).
[f] Excludes control bales.
[g] Interaction of contrast #2 and #3.

Table 10. Ruminal *in situ* disappearance kinetics of DM for the surface layer of large-round bales of mostly orchardgrass or alfalfa stored from July 2006 until April 2007 at Marshfield, Wis.

Treatment		Fraction[a]					
		A	B	C	Lag Time	Kd[b]	Disappearance[c]
Wrapping Type	Storage Site	(% of DM)			(h)	(/h)	(% of DM)
	Initial[d]	37.5	41.5	21.0	1.75	0.121	63.8
Net	Control[e]	37.9	40.8	21.3	1.25	0.136	65.4
Net	Elevated[f]	36.7	42.9	20.4	1.46	0.118	64.3
	Ground[g]	36.1	41.9	21.9	1.41	0.092	61.2
Sisal twine	Elevated	35.8	42.9	21.3	1.36	0.103	62.0
	Ground	36.1	41.3	22.6	1.52	0.119	62.5
	SEM	0.30	0.64	0.52	0.282	0.0057	0.55
Contrasts		$P > F$					
1) Control vs. all stored outside		< 0.001	0.043	0.665	0.551	< 0.001	< 0.001
2) Initial vs. control		0.291	0.398	0.668	0.209	0.055	0.046
3) Net wrap vs. sisal twine		0.114	0.611	0.121	0.989	0.286	0.384
4) Elevated vs. ground		0.650	0.048	0.008	0.846	0.338	0.023
5) Interaction[h]		0.157	0.614	0.835	0.701	< 0.001	0.002
Hay Type							
	Orchardgrass	35.6	45.7	18.7	1.64	0.092	62.7
	Alfalfa	37.7	38.0	24.2	1.28	0.138	63.7
	SEM	0.18	0.37	0.30	0.163	0.0033	0.32
	Contrast	< 0.001	< 0.001	< 0.001	0.122	< 0.001	0.021

[a] Fractions: A, fraction of total DM pool disappearing at a rate too rapid to measure; B, fraction of total DM pool disappearing at a measurable rate; C, fraction of total DM pool unavailable in the rumen.
[b] Kd, fractional rate constant.
[c] Calculated as A + B x ((Kd + Kp)/Kd), where Kp was the ruminal passage rate, which was arbitrarily set at 0.06/h (Hoffman et al., 1993).
[d] Bales sampled immediately after baling.
[e] Bales wrapped with net and stored under roof on wooden pallets.
[f] Bales stored outdoors without cover on wooden pallets.
[g] Bales stored outdoors without cover after placement directly on the ground.
[h] Interaction of contrast #3 and #4.

between CONTROL hays and all hays wintered outdoors (P < 0.001 and P = 0.043, respectively). In practical terms, these differences were relatively minor, with respective differentials of only 1.7 and 1.5 percentage units. Fraction C, which is unavailable in the rumen, was not affected (P = 0.665) by outside wintering; therefore, changes in the partitioning of DM associated with weathering occurred primarily via minor shifts from soluble or immediately available forms to those that disappear ruminally at a measurable rate. Estimates of Kd were slower for the 0.15-m surface layer of hays stored outdoors than for CONTROL hays (0.108/h vs. 0.136/h; P < 0.001), which also contributed to concomitant differences of relatively limited magnitude for effective ruminal disappearance of DM (62.5% vs. 65.4%; P < 0.001). The surface layer of CONTROL hays did not differ (P ≥ 0.291) from INITIAL hays for any aspect of DM partitioning or discrete lag time (P = 0.209). There was a tendency (P = 0.055) for CONTROL hays to disappear ruminally at a faster rate than INITIAL hays, which contributed to a small, but significant (65.4% vs. 63.8%; P = 0.046), advantage for effective ruminal disappearance. For bales wintered outdoors, the use of net wrap offered no advantage over sisal twine with respect to any kinetic parameter (P ≥ 0.114). Breaking soil contact by elevating bales resulted in greater (P = 0.048) estimates of Fraction B, and reduced estimates of Fraction C (P = 0.008); however, the magnitude of these shifts in DM partitioning was very small, and effective ruminal disappearance was greater for bales elevated on pallets by only 1.3 percentage units (63.2% vs. 61.9%; P = 0.023). Estimates of ruminal disappearance rate were affected (P < 0.001) by the interaction of wrapping method and soil contact. The NET-EL bales exhibited a more rapid Kd than NET-GR bales (0.118/h vs. 0.092/h); however, the opposite relationship occurred when TW-EL and TW-GR bales were compared (0.103/h vs. 0.119/h). The tying method × soil contact interaction observed for Kd likely contributed to an interactive relationship (P = 0.002) between TW-EL, TW-GR, NET-EL, and NET-GR for effective ruminal disappearance. The NET-EL treatment exhibited a numerically greater estimate than NET-GR (64.3% vs. 61.2% of DM), while the differential between TW-EL and TW-GR was small (62.0% vs. 62.5%). Contrasts of orchardgrass and alfalfa hays wintered during 2006-2007 indicated predictable differences (P ≤ 0.021) between hay types for all kinetic parameters except lag time (P = 0.122). Differing estimates of Kd (0.138/h vs. 0.092/h; P < 0.001) reflected the associated respective proportions of alfalfa and grass in each hay type, and these estimates were consistent with other reports for alfalfa and orchardgrass harvested at mid-bloom and the second node stage of growth, respectively (Hoffman et al., 1993). However, the effective ruminal disappearance calculated at a rapid passage rate (0.060/h) differed (P = 0.021) between hay types by only 1.0 percentage unit.

For 2007-2008 (table 11), differences were observed between hay types for all kinetic parameters (P ≤ 0.006).

Table 11. Ruminal *in situ* disappearance kinetics of DM for the surface layer of large-round bales of mostly orchardgrass or alfalfa stored from June 2007 until May 2008 at Marshfield, Wis.

Treatment		Fraction[a]					
		A	B	C	Lag time	Kd[b]	Disappearance[c]
Wrapping Type	Storage Site	(% of DM)			(h)	(/h)	(% of DM)
	Initial[d]	32.5	41.3	26.2	1.97	0.085	56.0
Net	Control[e]	32.9	43.5	23.5	1.76	0.069	55.7
Net	Elevated[f]	31.2	43.7	25.1	2.13	0.066	53.5
	Ground[g]	32.7	39.7	27.6	2.17	0.084	54.5
Sisal twine	Elevated	30.8	43.2	25.9	2.82	0.079	54.3
	Ground	31.0	42.5	26.5	2.51	0.077	53.5
	SEM	0.30	0.64	0.52	0.282	0.0057	0.55
Contrasts		*P > F*					
1) Control vs. all stored outside		< 0.001	0.084	< 0.001	0.044	0.269	0.008
2) Initial vs. control		0.338	0.018	0.001	0.611	0.049	0.646
3) Net wrap vs. sisal twine		0.001	0.066	0.761	0.073	0.654	0.786
4) Elevated vs. ground		0.006	< 0.001	0.005	0.635	0.189	0.906
5) Interaction[h]		0.026	0.011	0.063	0.538	0.089	0.109
Hay Type							
	Orchardgrass	29.9	44.9	25.2	2.83	0.066	52.3
	Alfalfa	33.9	39.7	26.4	1.62	0.088	56.9
	SEM	0.18	0.37	0.30	0.163	0.0033	0.32
	Contrast	< 0.001	< 0.001	0.006	< 0.001	< 0.001	< 0.001

[a] Fractions: A, fraction of total DM pool disappearing at a rate too rapid to measure; B, fraction of total DM pool disappearing at a measurable rate; C, fraction of total DM pool unavailable in the rumen.
[b] Kd, fractional rate constant.
[c] Calculated as A + B × ((Kd + Kp)/Kd), where Kp was the ruminal passage rate, which was arbitrarily set at 0.06/h (Hoffman et al., 1993).
[d] Bales sampled immediately after baling.
[e] Bales wrapped with net and stored under roof on wooden pallets.
[f] Bales stored outdoors without cover on wooden pallets.
[g] Bales stored outdoors without cover after placement directly on the ground.
[h] Interaction of contrast #3 and #4.

Although not compared directly, estimates of Kd were numerically slower for both hay types during the second year of the study, which is likely related to the advanced (fully-headed) growth stage of the orchardgrass and the greater percentage of quackgrass within the alfalfa hays. These factors contributed to estimates of effective ruminal disappearance that were depressed by 10.4 and 6.8 percentage units relative to the previous year for orchardgrass and alfalfa hays, respectively. Unlike 2006-2007, there were numerous significant contrasts comparing storage treatments; however, these were primarily confined to relatively small differences in fractions A, B, and C, rather than Kd or effective ruminal disappearance. The estimate of Kd for INITIAL was greater than that for CONTROL hays (0.085/h vs. 0.069/h; $P = 0.049$), but other comparisons for Kd did not differ ($P \geq 0.089$). Similarly, CONTROL hays exhibited greater effective disappearance of DM than all hays wintered outdoors (55.7% vs. 54.0%; $P = 0.008$), but magnitude of this difference was very small, and of minor nutritional relevance. Effective disappearance of CONTROL and INITIAL hays did not differ ($P = 0.646$), nor did any other contrast comparing estimates of effective ruminal disappearance ($P \geq 0.109$) for 2007-2008.

Discussion

Over two years in which precipitation was either below or well above expected norms for central Wisconsin (table 1), the nutritive value of the 0.15-m surface layer for orchardgrass or alfalfa hays that were wintered outdoors varied only marginally from samples obtained from the associated bale core, or from the surface layer of CONTROL bales stored indoors. During the relatively dry conditions observed during 2006-2007, the energy density (TDN) of the 0.15-m surface layer of all bales wintered outdoors was depressed by 1.4 percentage units (60.8% vs. 59.4%) relative to CONTROL bales. With much greater precipitation during the 2007-2008 storage period, this differential increased to only 3.2 percentage units (57.3% vs. 54.1%). If these results are extrapolated to a whole-bale basis, the small differences observed for the 0.15-m surface layer are reduced further because this exposed layer comprised only about 40% of the total volume for these bales. There was little evidence that the nutritive characteristics within the bale core were affected in any biologically relevant manner by weathering, regardless of storage treatment.

Generally, these observations were largely corroborated with our *in situ* evaluations of ruminal DM disappearance in which the effective ruminal disappearance of DM obtained from the surface layer varied by only 2.9 percentage units (65.4% vs. 62.5%) between CONTROL and all hays wintered outdoors during 2006-2007. This differential was even narrower (1.7 percentage units; 55.7% vs. 54.0%) the following year, which included substantially greater precipitation. It should be noted that these comparisons are somewhat empirical in nature, and do not consider any possible effects on animal acceptability or preference that may affect voluntary intake and subsequent productive performance.

Any general comparisons of our forage quality results with studies evaluating outdoor storage options for large-round bales in other climates are somewhat problematic, and are confounded by several specific factors. An incomplete list includes: i) different sampling procedures for the exposed surface of the bale; ii) vast discrepancies in species composition within the evaluated hays; and iii) variations in haymaking equipment and operator experience, which can affect the shape and density of the experimental bales. Despite these factors, our results are consistent with the premise that microbial activity and associated depressions in forage nutritive value can be restricted by the cold winter temperatures observed commonly throughout northern climates.

Although our storage treatments had limited practical effect on overall nutritive value or kinetics of ruminal DM disappearance for the surface layer, wrapping method and soil contact clearly affected recoveries of DM following outdoor storage. Wrapping method had no effect on recovery of DM following the 2006-2007 season in which precipitation was below normal. During the wetter conditions observed during the following year, bales wrapped with twine recovered less DM than those wrapped with plastic net, but this response was primarily associated with TW-GR bales. These results are consistent with work in Kansas (Taylor et al., 1994), in which net wrap could not be justified over plastic twine strictly on the basis of reduced weathering losses in arid environments; however, results also suggested net wrap could be more advantageous under less-desirable weather conditions for outdoor storage. Other studies (Shinners et al., 2009) have shown consistent advantages in DM recovery with net-wrapped bales. Additional benefits of net wrap, such as faster wrapping of bales in the field and reduced wrapping losses (Shinners et al., 2009), as well as the long-term structural integrity of the bale, have been clearly established. The latter factor is critical if the bale must be moved multiple times before cash sale and/or feeding. Sisal twine can be advantageous when hay is offered in ring-type feeders because any twine not recovered is ultimately biodegradable, and of reduced risk to entangle the feet and legs of livestock compared to plastic wrappings, and especially plastic twine.

An important management option for improving recoveries of DM is breaking direct contact between the bale and the soil surface. For bales wintered outdoors, breaking soil contact by elevating bales on wooden pallets resulted in respective 2.8- and 3.5-percentage unit advantages in DM recovery for the first and second years of the study. However, these advantages were smaller than those obtained by comparing CONTROL bales with any of the outside wintering options. It should be noted that the outdoor storage treatments, including those placed directly on the soil surface, conformed to typical recommendations for site selection, as well as bale placement and orientation (Ball et al., 1998). These recommendations are designed to encourage drainage of surface water away from bales, maximize exposure of rounded sides to the sun, increase penetration of sunlight to the soil surface, and encourage good air movement throughout the bale storage site. Adherence to these recommended practices may have limited differences across storage treatments. The overall recovery of DM for all bales (n = 74) wintered outdoors over two years was 91.4%, which is somewhat greater than observed by others (Anderson et al., 1981; Collins et al., 1995; Norman et al., 2007; Turner et al., 2007). Although difficult to assess, it is possible that the physical layout for placement of bales may have contributed to the relatively high recoveries of DM. Each bale was positioned with approximately 1 m of open space between bales on all sides. While this was a procedural compromise to guarantee the independence of each experimental unit (bale), it also may have facilitated more rapid drying following rainfall events relative to storage in rows with bales butted against each other that is common in most production situations.

Conclusions

Although statistically significant differences were detected across storage options, the nutritional composition and energy density of the 0.15-m surface layer for bales wintered outdoors differed only marginally from the surface layer of control bales stored indoors. Therefore, the most meaningful criterion for monitoring outdoor storage options for large-round bales in this study was simply the recovery of DM. Within this context, recoveries of DM always were greatest with indoor storage. For bales wintered outdoors, our overall mean recovery of DM was 91.4% across all storage options. This conservation efficiency is somewhat better than described in some other reports, particularly those conducted in warmer climates that assessed storage options comparable to those in our study. While this observation is not proof that losses of DM are limited by colder climatic norms, it is consistent with that premise. If bales must be wintered outdoors, breaking direct contact between the bale and the soil surface improved recoveries of DM by 3.1 percentage units over both years of the study, and therefore should be considered an effective management option. The effects of wrapping type on recoveries of DM were less consistent. During 2006-2007, wrapping type had no effect on recoveries of DM following wintering outdoors; however, under the wetter conditions observed for 2007-2008, recoveries of DM were improved by about 2.4 percentage units when bales were wrapped with plastic net. The results of these studies suggest that elevating bales off of the soil surface and wrapping bales with net offer the highest probability of maximizing recovery of DM following winter storage.

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